# The Role of the Coherence Length in Exclusive Electroproduction of Vector Mesons off Nuclei at Moderate Energies*

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## ABSTRACT

The variation of the coherence length $l_c = 2\nu/(Q^2+m_V^2)$ in virtual photoproduction of vector mesons off nuclei as a function of the photon energy $\nu$ or virtuality $Q^2$ results in dramatic changes in the values of the nuclear transparency. Color transparency effects can be easily mixed up with the effects of the coherence length in incoherent photoproduction on nuclei.

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# 1 Color transparency in exclusive electroproduction of vector mesons off nuclei

Virtual photoproduction of vector mesons off nuclei was suggested in [1] as an effective way for detecting color transparency (CT) effects. One can change the size of the produced wave packet by varying $Q^2$, but keeping the photon energy high and fixed. This is different from quasielastic $(e, e'p)$ and $(p, 2p)$ reactions, where one may have high energy only at the expense of high $Q^2$, i.e. very small cross section. Recently the E665 experiment [2] has claimed to confirm, although with a poor statistics, the CT effects predicted in [1].

Analogous experiments are planned in the CEBAF-HERMES-ELFE energy range: Rising $Q^2$-dependence of nuclear transparency is expected to be a signal of CT. However, we would like to warn in this paper against straightforward application of the high-energy predictions of [1] at moderate energies. We demonstrate that also effects of the coherence length provide a steep variation of nuclear transparency with $Q^2$, which can mock CT effects or make interpretation of the data more ambiguous.

We work in the Glauber approximation, which is usually supposed to be a base line for CT studies. The correct formula for incoherent (virtual) photoproduction of vector mesons off nuclei was not known in the literature, and we present it here.

# 2 Coherence length

Vector mesons produced at different longitudinal coordinates have relative phase shifts $q_L \Delta z$ due to the difference in the virtual photon and the meson longitudinal momenta $q_L = (Q^2 + m_V^2)/2\nu$. Only those mesons interfere constructively which are produced sufficiently close to each other: $\Delta z \leq l_c$, where

$$l_c = \frac{1}{q_L} = \frac{2\nu}{Q^2 + m_V^2} \tag{1}$$

is called coherence length. It can be also interpreted as a lifetime of the hadronic fluctuation of the photon. If $l_c$ is much shorter that the mean inter-nucleon distance, there is no nuclear shadowing in the initial state. However, if $l_c$ is much longer than the mean free path of the vector meson in the nucleus or the nuclear radius, nuclear suppression is expected to be stronger than that in the low-energy limit.

Thus, the energy- and $Q^2$-variation of $l_c$ results in dramatic changes in the nuclear transparency. These variations may easily be mixed up with CT effects in some cases. For the photoproduction of charmonium the transition region covers the energies from a few tens to a few hundreds of GeV. For light vector meson $(\rho, \omega, \phi)$ the transition energy range is an order of magnitude lower.

# 3 Incoherent electroproduction of vector mesons

The formula for the exclusive incoherent production of vector mesons which incorporates the effects of the coherence length is derived for the first time[§] in ref. [4]. The nuclear transparency for the cross section integrated over momentum transfer can be represented as,

$$Tr_{inc}(\gamma^* A ß V X) = Tr_1 + Tr_2 - Tr_{coh} \ , \tag{2}$$

where the first term

$$Tr_1 = \frac{1}{\sigma_{in}^{VN}} \int d^2b \left[1 - e^{-\sigma_{in}^{VN} T(b)}\right] \tag{3}$$

corresponds to the case where the vector meson is produced on the same nucleon in both interfering amplitudes.

If the nucleons are different, the corresponding term $Tr_2$ in eq. (2) reads,

$$\begin{aligned} Tr_2 = \frac{\sigma_{tot}^{VN}}{2\sigma_{el}^{VN}} (\sigma_{in}^{VN} - \sigma_{el}^{VN}) \int d^2b \int_{-\infty}^{\infty} dz_2 \ \rho(b, z_2) \int_{-\infty}^{z_2} dz_1 \ \rho(b, z_1) \ \times \\ e^{iq_L(z_2 - z_1)} \ \exp\left[-\frac{1}{2}\sigma_{tot}^{VN} \int_{z_1}^{z_2} dz \rho(b, z)\right] \exp\left[-\sigma_{in}^{VN} \int_{z_2}^{\infty} dz \ \rho(b, z)\right] \end{aligned} \tag{4}$$

The two first terms in eq. (2) correspond to the sum over all final states of the nucleus via completeness. For this reason the third term which represents coherent production has to be subtracted in eq. (2).

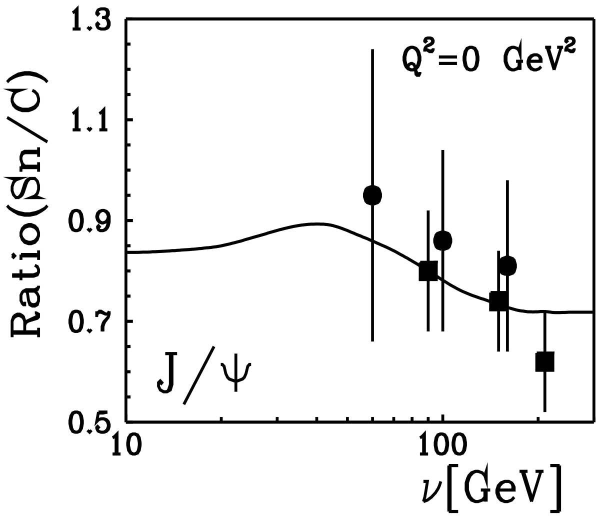
$$Tr^{coh}(\gamma^* A ß V A) = \frac{(\sigma_{tot}^{VN})^2}{4\sigma_{el}^{VN}} \int_{-\infty}^{\infty} d^2b \left| \int dz \ \rho(b, z) \ e^{iq_L z} \exp\left[-\frac{1}{2}\sigma_{tot}^{VN} \int_z^{\infty} dz' \rho(b, z')\right] \right|^2 \tag{5}$$

Here $\rho(b, z)$ is the nuclear density and $b$ the impact parameter. $T(b) = \int_{-\infty}^{\infty} dz \rho(b, z)$ is the nuclear thickness function.

In low-energy limit only the term eq. (3) survives. In the high-energy limit, $q_L \ll 1/R_A$, the nuclear transparency is the same as in quasielastic V-A scattering, what can be interpreted as a result of the fluctuation $\gamma^* ß V$ long in advance of the nucleus. Thus nuclear transparency of incoherent electroproduction of vector mesons is expected to decrease with $\nu$. This was

[§]One can find a formula for incoherent photoproduction of vector mesons in ref. [3] which differs from our eqs. (2)–(4), and we consider it as incorrect. That formula underestimates available data on real photoproduction of $\rho$ off nuclei (see corresponding discussion in ref. [3]). Our calculations nicely agree with the data.

predicted in [5, 6] for the energy dependence of $J/\Psi$ photoproduction and confirmed by the NMC experiment as is shown in fig. 1 [6]. Another example of the energy dependence of the nuclear transparency for real photoproduction of $J/\Psi$ on Beryllium is shown in fig. 2.



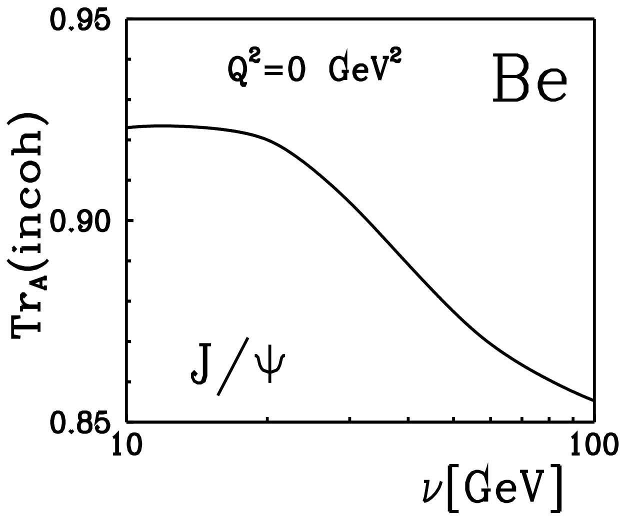




Figure 1: Energy-dependence of ratio of $J/\Psi$ real photoproduction cross sections on $Sn$ to $C$ [7]. The non-trivial dependence only originates from the variation of the coherence length with $\nu$

Figure 2: The same as in fig. 1 for nuclear transparency on Be.

Analogous calculations for the electroproduction of $\rho$-mesons on Iron are shown in fig. 3as function of energy at different values of $Q^2$. The energy variation of nuclear transparency is much steeper than for charmonium due to the larger cross section.

The shrinkage of the coherence length as a function of $Q^2$ at fixed energy, causes a growth of nuclear transparency with $Q^2$, a behaviour which resembles CT and should be taken into account searching for CT. Examples of $Q^2$-dependence for $\rho$-meson photoproduction versus photon energy $\nu$ are shown in fig. 4 Nuclear transparency steeply increases and then saturates at high $Q^2$. Note that nuclear transparency cannot reach unity at medium energies, even in presence of CT. $Tr(Q^2)$ saturates at about the same level as is shown in fig. 4. Indeed, the predicted saturation in the Glauber approximation signals that the coherence length becomes negligibly short, i.e. there is no room for the full CT.

Note that our prediction of steep $Q^2$ dependence of nuclear transparency at moderate energy is in variance with the results of [7] which expect nearly $Q^2$-independent nuclear transparency for electroproduction of $\phi$-meson at $\nu = 8\ GeV$. The reason of so large discrepancy is neglection in [7] the effects of coherence length, which was fixed at zero.

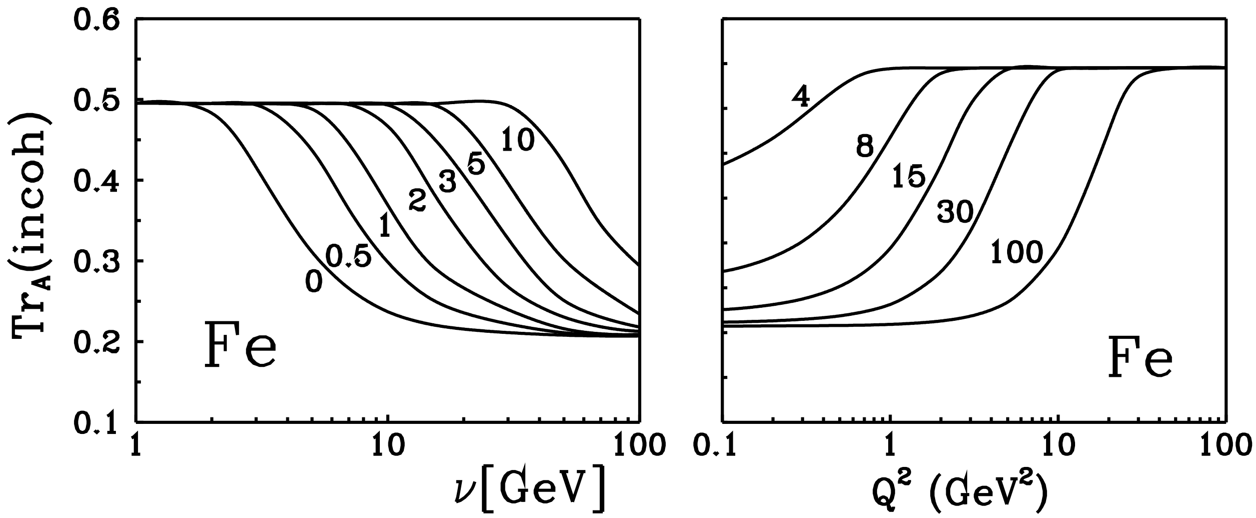



Figure 3: Energy dependence of nuclear transparency in virtual incoherent photoproduction of $\rho$-meson on $Fe$ for different values of $Q^2$.

Figure 4: $Q^2$-dependence of nuclear transparency in virtual incoherent photoproduction of $\rho$-meson on $Fe$ for different values of $\nu$

# 4 Coherent electroproduction of vector mesons

In this case the nuclear transparency has the form of eq. (5) (see for instance [3]),

The results of calculation of energy dependence of nuclear transparency at different values of $Q^2$ for coherent photoproduction of $\rho$-mesons are plotted in fig. 5.

We present in fig. 6 the Glauber model predictions for variation of nuclear transparency as function of $Q^2$ in $\rho$-meson photoproduction at different photon energies. In this case the nuclear transparency is a decreasing function of $Q^2$, i.e. has an opposite trend compared to what is supposed to be a signal of CT. We conclude that coherent virtual photoproduction of vector mesons at moderate energies is a better reaction for CT studies that incoherent one.

Summarising, we demonstrate the importance of coherence length effects for incoherent and coherent exclusive electroproduction of vector mesons off nuclei. These effects provide a steep variation of nuclear transparency as function of energy and virtuality of the photon.

The Glauber formula, which we use for incoherent production is new.

We use the eikonal Glauber approximation *on purpose.* Inclusion of the excited intermediate states would be equivalent to the CT effect. However, we are interested in a base line for study of CT. Note that the effect of $Q^2$-dependence of nuclear transparency in $(e, e'p)$ reaction due to inelastic shadowing, discussed in section 2, is irrelevant in this case. Indeed, in $(e, e'p)$ it originates from energy dependence, but the photon energy is fixed in the photoproduction experiments.

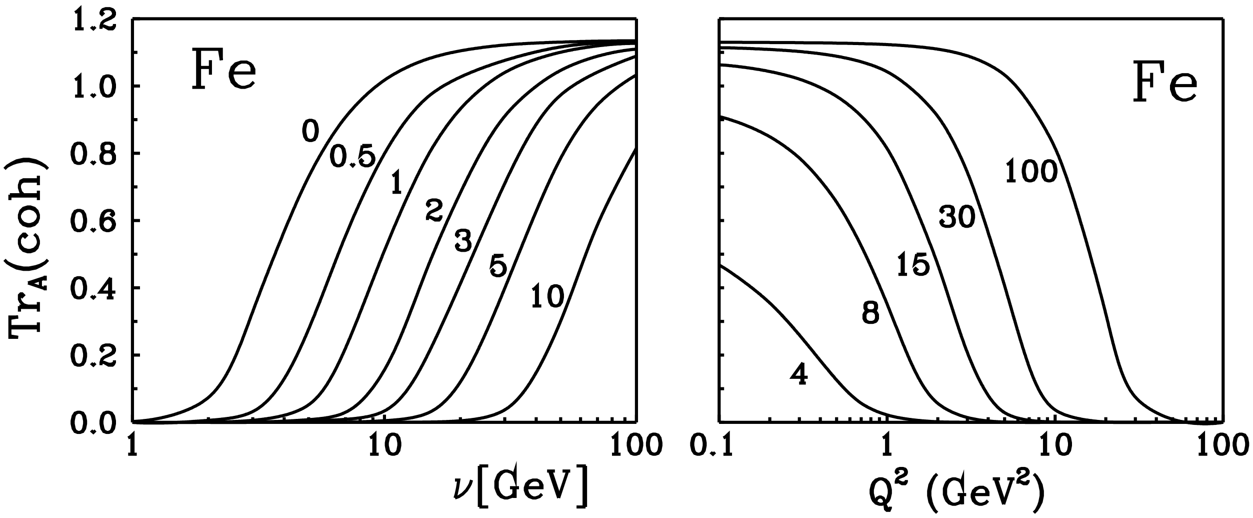



Figure 5: The same as in fig. 3, but for coherent production.

Figure 6: The same as in fig. 4, but for coherent production.

It was found in [5, 1] that for real photoproduction of ground states of vector mesons these corrections are quite small. At moderate energies they are small even at high $Q^2$, since as is argued above the nuclear transparency does not reach unity at high $Q^2$, but saturates at about the same level as in the Glauber approximation.

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# References

[1] B.Z. Kopeliovich, J. Nemchik, N.N. Nikolaev and B.G. Zakharov, Phys. Lett **B324** (1994) 469; Phys. Lett. **B309** (1993) 179

[2] M.R. Adams et al., Phys. Rev. Lett. **74** (1995) 1525

[3] T.H. Bauer et al., Rev. Mod. Phys. **50** (1978) 261

[4] J. Hüfner, B.Z. Kopeliovich and J. Nemchik, paper in preparation

[5] B.Z. Kopeliovich and B.G. Zakharov, Phys. Rev. **D44** (1991) 3466

[6] O. Benhar, B.Z. Kopeliovich, Ch. Mariotti, N.N. Nikolaev and B.G. Zakharov, Phys. Rev. Lett. **69** (1992) 1156

[7] O. Benhar, B.G. Zakharov, N.N. Nikolaev and S. Fantoni, Phys. Rev. Lett. **74** (1995) 3565